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Exploring the thermal limits of IR-based automatic whale detection (ETAW)

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LONG-TERM GOALS

Growing concerns that aquatic noise produced during naval exercises and offshore seismic surveys may be harmful to marine mammals, have led an increasing number of regulating agencies to request mitigation measures when issuing permits for such surveys in their nations' EEZ. The most common measure is to implement a "marine mammal watch", a team of observers that scans the ship's environs for signs of presence of marine mammals to trigger a shutdown of the hydroacoustic source when marine mammals are entering a predefined *exclusion zone*.

Marine mammal observers usually scan the ship's environs for whales using binoculars or the naked eye. Sightings mostly rely on spotting a whale's blow, which might rise to a height of several meters but is visible for a few seconds only. Hence, in combination with the whales' prolonged dives, sighting opportunities are rare, which, in addition to the limited field of view and finite attention span of human observers, renders this method far from optimal, even during fair weather and daytime. During darkness it is not feasible.

Our long-term goal is to overcome these difficulties and to develop a reliable, automatic whale detection system for the full range of oceanic environmental conditions (wind, sea surface temperature) and species. To this end, we developed a ship-based thermal imaging system for automated marine mammal detection, consisting of an actively stabilized, spinning IR camera and an algorithm that detects whale blows on the basis of their thermal signature. So far, this technology has been tailored to and tested under cold (SST < 10°C) water conditions only, as this is where the technology was expected to perform best. To adapt the technology to warmer environments and to test its performance there is the specific goal of this proposal.

OBJECTIVES

This project aims at a cost-efficient test of the thermal limits of the abovementioned IR based automatic whale detection technology by attempting to capture whale spouts during the northward humpback whale migration, which occurs annually rather close to shore near North Stradbroke Island, Queensland, Australia[1]. Based on the collected data, detector/classifier optimization shall be performed and ensuing system performance be tested by subsequent comparisons with concurrent visual observations.

APPROACH

By obtaining continuous IR video footage during two[1] successive northward humpback whale migrations and collecting concurrent independent (double blind) visual observations (modified cue counting), a data base will be created to:

- Determine the performance of the imaging device in warm waters;
- Determine the performance of the existing automatic detector in warm waters;
- Develop optimized auto-detection algorithms for the warm water realm;
- Determine the performance of the optimized detector in warm waters;
- Generate additional baseline data on locomotive behavior of migrating humpbacks (providing the proposed technology proves technically feasible);
- Generate, for the first time, data on night time humpback migration; (providing the proposed technology proves technically feasible);

At AWI, key individuals for this project are Daniel Zitterbart, overlooking the system development, and Elke Burkhardt, overlooking the concurrent sighting data acquisition. The field activities in Australia were supported by Mike Noad, University of Queensland, who has organized many whale surveys off North Stradbroke Island, the field activities on Kauai are supported by Aude Pacini, researcher at the Mammal Research Program, Hawaii Institute of Marine Biology, University of Hawaii, School of Ocean and Earth Science and Technology.

WORK COMPLETED

The 2014 field season was conducted on North Stradbroke Island, Queensland, Australia between 06.06.2014 and 20.07.2014, with a primary data collection period from 14.06.2014 until 14.07.2014. The main aim for the 2014 field season was to collect IR video footage of blowing whales, whilst concurrently recording their position with visual observations through a theodolite. We deployed a team of 2 (IR technology) plus 6 (visual observers) researches, with additional local support. The high abundance of blows/whales also allowed allocating 6 days of expedition time to acquire a first data set for (double blind) visual-MMO/IR comparisons. Further details are given in the 2014 annual report.

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[1] Please note, that for reasons laid out in the main text below, we modified the original plan (as described here) of two consecutive field seasons at Stradbroke Island in 2014 and 2015 to one field season at Stradbroke Island in 2014 and one field season on Kauai in 2016.

In FY 2015, documentation of this field study was prepared (expedition report available on request) and thermographic data was screened for whale blows on the basis of MMO sightings. This resulted in a substantial data set (see results) which provides the basis for algorithm testing and development.

Performance of the two components of the cold water detection algorithm (i.e., the *detector* and the *classifier*) was explored using the acquired warm water thermographic data. Performance differed significantly for these two stages (see RESULTS). The findings instigated the development of a new *detector* featuring improved computational performance which we aim to have implemented for the next field trials.

Based on the experiences made during the first field trial, we developed a tool to synchronize timestamps from the various observation tools for the second field trial. We also developed various scripts and parsers to log environmental data from the weather station and visibility recorder.

Preparation of the expedition report included a detailed reflection on the informative values of the various metrics and protocols used, including consideration biases and study designs. This led to a reconsideration of the requirements for potential field sites. For the Stradbroke Island site in particular, visual observations are facilitated by the whales preferred migration directions, allowing the observers to capture nearly all animals by focusing their attention on a very narrow strip of water. This renders detection performance statistics for visual observers from the Stradbroke site unfit to represent the (aimed for) open ocean conditions, where whales might turn up anywhere relative to the ship. Based on these findings, we sought and evaluated new potential field sites with less predictability re whale behavior, organized on-site support, and made necessary arrangements to execute the next field study.

RESULTS

The primary goal of this field season was to acquire sufficient data to be able to train the SVM (support vector machine) of the automatic whale detection algorithm under warm water conditions. This goal (the collection of sufficient data) has been fully achieved. In a first screening of the IR imagery, we visually identified 2330 cues (mostly blows) in a total of 511 encounters (pods).

Particularly with regard to the latter visual-MMO/IR comparisons, it became clear during the field period and the ensuing discussions in writing the field report, that the high directionality and abundance of whales at the Australian filed side is in fact biasing comparisons between MMOs and IR and results are only of limited power when trying to describe relative sighting probabilities for an open ocean situation. Hence it was decided to abandon the Stradbroke Island field site and to seek a location where whale swim directions are less directional and animals are less frequent, yet still reliably present close to the coast. After evaluation of information on the Azores, the California coast and the Hawaiian Islands, our final choice narrowed on Kauai, with known seasonal presence of humpbacks. We identified field sites at the North and South shore, which will be occupied in Jan-Mar 2016.

Applying the cold-water tested detection algorithm on the warm-water data in Australia, revealed a lack in computational performance. The simple short-term-average/long-term-average algorithm that was used to select thermal anomalies which might resemble a whale blow responded primarily to thermal noise caused by breaking waves (which were very frequent due to surf along the shore). This resulted in thermal anomalies from whales being ranked not high enough, to pass the detection step

and being forwarded to the classifier. Contrastingly, the classification algorithm, as based on the cold-water trained support-vector machine, was performing well on the whale blows that passed the detection step.

To overcome the detector bottleneck, we developed a new detection algorithm (publication in preparation) which however depends on increased computational power, prohibiting its implementation in Matlab™ but requiring the implementations of core components in C++.

To re-train the classification algorithm, we reviewed 3053 thermal anomalies considered by MMOs as whale signatures and categorized them in 9 classes (wave, blow, back, breach, slap, boat, undefined cue, undecided, deleted).

We tested the classification performance using a deep-learning convolutional neural net (CNN) to classify 20000 manually annotated thermal anomalies from the cold-water regime into 6 different classes (wave, blow, structure, bird, ice and unknown). It turned out, that the results of the SVM and the Neural Network were comparable in terms of positively detected whale blows and false positives, yet with a much higher computational load for the Neural Network than the for the SVM. To facilitate this comparison, a framework that allows to train a CNN and classify the small video snippets that are produced by the detector using this CNN was developed. This data will be used in addition to the warm-water data used to develop a classifier. The current classifier used is a binary decision making support-vector-machine (SVM).

To facilitate easy review of thermal anomalies classified as whale blow without the need of a workstation, we designed and developed an App for mobile devices (i.e. iPad) that alerts the MMO of a suspected whale detection and presents him the data in a continuous loop including a geo-referenced display of the detection of the last 30 min.

IMPACT/APPLICATIONS

Our deliberations result in an aspect of wider relevance: Performance comparisons across different observation/ detection platforms (e.g. MMOs, AIMMMS or PAM) require an *a-priori* definition of a metric bearing relevant informative value. This metric needs careful consideration prior to going in the field, taking into consideration the various platform specific uncertainties regarding positioning. Our results suggest, that this metric should mimic the operational challenge as close as possible, i.e. including specific exclusion radii. For example, an "in-time detection" metric, answering YES or NO to the question if an animal was detected by the method prior to entering a presumed exclusion zone, might be fit to quantify performance across platform, whereas a metric comparing PAM and visual detections directly cue by cue will fail, as these are likely not to occur simultaneously. For the second field season, we plan implement a "mitigation protocol" and corresponding metric, i.e. MMO and AIMMMS operators will make *in-situ* mitigation decision, to latter compare these against each other. With assistance of recorded data, sightings can be verified in the aftermath, to also extract the amount of false alerts for each method.

TRANSITIONS

Rheinmetall Defence Electronics, Bremen, Germany, has acquired a license of the AWI-developed data acquisition software and current cold-water detection kernel and is marketing the entire system (the FIRST-NAVY sensor head and the AWI-built software components) under the acronym

AIMMMS (Automatic Infrared Marine Mammal Mitigation System). Any further software developments made during or sponsored by ONR through ETAW do not fall under the current licensing agreement.

RELATED PROJECTS

We have meanwhile been funded by the German Ministry for Education and Research (BMBF) to test the capability of a thermographic dual-band IR camera, which holds the potential of providing an improved S/N ratio.

PUBLICATIONS

Note: The papers/reports listed hereinafter describe the current state of development with regard to "cool water" deployments and basically describes the *prior knowledge* that is being entered into the ETAW (i.e. this) project by AWI.

Zitterbart DP, Kindermann L, Burkhardt E, Boebel O (2013) Automatic Round-the-Clock Detection of Whales for Mitigation from Underwater Noise Impacts. PLoS ONE 8(8): e71217. doi:10.1371/journal.pone.0071217 [published, refereed]

Boebel O., Bombosch A., Burkhardt E., Cammereri A., Kindermann L., Richter S., Zitterbart DP. MAPS: Marine Mammal Perimeter Surveillance. In: Boebel O., editor. The Expedition of the Research Vessel "Polarstern" to the Antarctic in 2012/2013 (ANT-XXIX/2). Bremerhaven: Reports on Polar and Marine Research. [in press]

Burkhardt E., Lanfredi L., Richter S., Boebel O., Kindermann L., Zitterbart DP. MAPS: Marine Mammal Perimeter Surveillance. In: Lucassen M., editor. The Expedition of the Research Vessel "Polarstern" to the Antarctic in 2012 (ANT-XXVIII/4). Bremerhaven: Reports on Polar and Marine Research. 652 , 89 p. 2012 .

Richter S, Müller M, Boebel O, Kindermann L, Zitterbart DP (2012) MAPS: Marine Mammal Perimeter Surveillance. In: Kattner G, editor. The Expedition of the Research Vessel "Polarstern" to the Antarctic in 2011/12 (ANT-XXVIII/2). Bremerhaven: Reports on Polar and Marine Research. pp. 56.

Boebel O., Bombosch A., Kindermann L., Zitterbart DP. MAPS: Marine Mammal Perimeter Surveillance In: Fahrbach E, editor. The Expedition of the Research Vessel "Polarstern" to the Antarctic in 2010/2011 (ANT-XXVII/2). Bremerhaven: Reports on Polar and Marine Research, 634,102 - 110, 2011. (PDF)

PATENTS

Note: The patent below describes the current state of technology and basically describes the prior knowledge that is being entered into the ETAW (i.e. this) project by AWI.

Zitterbart DP, Kindermann L, Boebel O; Method for automatic real-time monitoring of marine mammals, US Patent 8,941,729 B2 from Jan 27 2015.

Russian and

HONORS/AWARDS/PRIZES

Zitterbart DP, AWI, „BRIESE-award for Marine Science”. Briese Schiffahrts GmbH & Co. KG.